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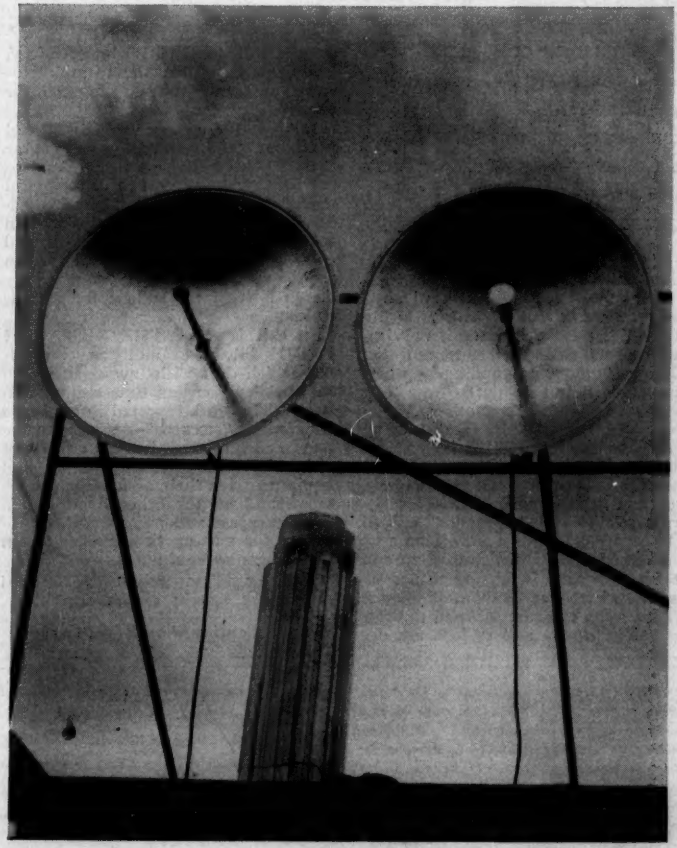

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WHAT IS RESEARCH?

When those who are uninformed think of research, they mentally picture white-frocked scientists either busily engaged in experiments involving multicolored, steaming retorts and distillation columns, or standing by while man-made lightning darts from one electrical apparatus to another. When pressed, some may dimly recall hearing of "economic research"—chiefly conducted by longhaired college professors, according to report—and a few have even heard that research in some abstruse science called "physics" was of help in developing the atom bomb.

Even scientists and engineers are not always clear as to what constitutes research and its brother, "development." All too often they are inclined to draw definitions closely and to look askance at studies in such fields as sociology, feeling perhaps that the variables involved are usually too many for scientific control.

Industrial engineers and industrial psychologists, however, do not agree that definitive research is restricted to the field of the physical and biological sciences. To them, man and his behavior become predictable, within reasonable limits, through well-defined studies. Moreover, such studies often require special apparatus, whose proper design is itself the subject for investigation.

In this issue of THE RESEARCH ENGINEER, for example, are two articles which deal with investigations on industrial vision and time and motion study. The work reported in each case is definitely "research"—research on the one hand into quantitative statistics of industrial vision characteristics and equipment for their accurate measurement, and on the other hand into a more accurate and more versatile procedure for making time studies, again involving new equipment.

Webster defines research as "careful or diligent search; a close searching,"

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According to Webster, an *institute* is "an organization to promote art, science, or the like, as a society, college, or technical school." A *college*, similarly, is "a society of scholars incorporated for study or instruction, especially in the higher branches of knowledge; a university or one of its schools." Finally, a *school* is "a faculty for specialized higher education, usually within a university; as a medical or law school."

All of these definitions have meaning when considered in regard to the Georgia *Institute* of Technology, with its *colleges* and constituent *schools* of engineering and science. As will be noted, emphasis in these definitions is on instruction and study, and in all divisions at Georgia Tech every attempt is made to blend education ("instruction") and research ("study") for the betterment of students, teachers, and society.

BLAKE R. VAN LEER
President, Georgia Institute of Technology

EFFECTS OF WEATHER ON MICROWAVE PROPAGATION*

By J. E. BOYD**

During World War II, operational experience with radar and ultrahigh frequency communication equipment revealed that the propagation of ultrashort waves through the lower atmosphere is influenced greatly by meteorological conditions. Knowledge of microwave propagation phenomena has become increasingly important because of recent developments of microwave relay systems for long-distance telephone and television transmission. This article reviews some of the basic factors influencing propagation and summarizes the results of research conducted in this field at Georgia Tech during the past few years.

Since 1946, the Georgia Tech Engineering Experiment Station has been engaged in studies of the effects of weather on microwave propagation. Transmitters and receivers operating at frequencies of 9,400, 2,860, and 1,310 megacycles (with wave lengths of 3, 10, and 23 cm.) have been developed and utilized in a series of measurements over 50-mile paths between Georgia Tech and the mountains of North Georgia.

The primary purpose of these propagation measurements has been the determination of the effects of variations in atmospheric conditions on received signal strength at different frequencies in the microwave region. Consequently, the method of investigation employed involves the simultaneous recordings of signal strength at several microwave frequencies and the obtainment of atmospheric soundings and weather observations along the path of propagation. Statistical methods of analysis are then applied to the experimental data in an effort to correlate signal fluctuations with atmospheric variations.

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FACTORS INFLUENCING PROPAGATION

The propagation of microwaves over the earth's surface is influenced by various factors, including: (1) reflection by the earth's surface, (2) scattering by trees and other objects projecting above the surface, (3) absorption by atmospheric gases and water vapor, (4) absorption and scattering by rain, and (5) atmospheric refraction.

In radio propagation over a smooth reflecting surface the electromagnetic waves are transmitted to a receiver along two paths, a direct path and an indirect path (by reflection from the surface), as illustrated in Figure 1. Because of the difference in the lengths of these two paths, the direct and indirect waves usually arrive at the receiver with different phases, and constructive or destructive interference results. As a consequence of this interference between the direct and indirect waves, the received signal may be increased or decreased. Moreover, if the height of the receiver is continuously varied, the path difference also varies, and the received signal fluctuates between wide limits and may fade out completely for brief periods. For fixed transmitters and receivers over a reflecting plane, signal variations may still occur if atmospheric conditions

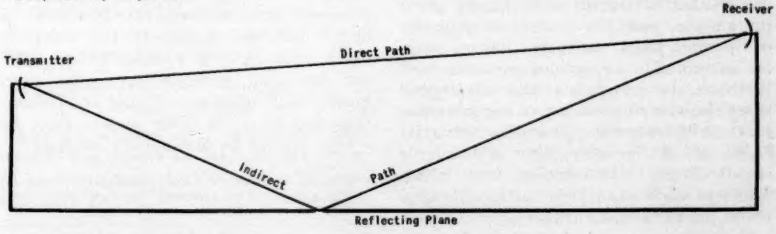

Figure 1. Microwave propagation over a reflecting surface.

differ along the paths and change with time. Consequently, reflection is an important factor in propagation over a smooth reflecting surface, such as the surface of the sea.

In propagation over rough, tree-covered terrain to a receiver well above the horizon, however, it has been found that the intensity of the reflected wave is greatly diminished, because of diffuse scattering. Since the Georgia Tech measurements were made over rough-terrain land paths which contained a high percentage of tree coverage, surface reflection probably had little effect on the received signals, so little in comparison with other propagation factors that it was disregarded in the studies reported here.

Signal absorption by atmospheric gases and water vapor is inappreciable at the frequencies used in the Georgia Tech measurements. Heavy rainfall, however, may cause considerable signal attenuation at the frequency of 9,400 mc., as will be shown later.

Except for the rare occasions when microwaves are attenuated by heavy rainfall, atmospheric refraction is the predominant factor in causing signal strength variations in microwave transmission over land through the lower atmosphere. For this reason, the causes and effects of atmospheric refraction have been studied at Georgia Tech in considerably more detail than the other factors which may influence radio-wave propagation

ATMOSPHERIC REFRACTION

If the atmosphere were homogeneous, electromagnetic waves such as light and microwaves would travel along straight lines in their passage across the earth's surface. As a result of changes in the density and composition of the air with height above the surface, however, the refractive index of the atmosphere varies, and the ray paths are curved. The amount of refraction and, therefore, the curvature of the rays depend upon the rate of variation of the refractive index with altitude. Since the refractive index, n, of the atmosphere differs only slightly from unity—varying from about 1.0004 at sea level to 1.0000 at great heights above the earth—the changes of n with altitude may appear insignificant, but the effects on propagation under some conditions are remarkable. At times, refraction may even be sufficient to cause the rays to follow the earth's curvature, so that radar is sometimes capable of detecting surface targets at ranges many times greater than the distance of the horizon.

For visible light waves, the excess of the index of refraction of the atmosphere, $(n-1)$, is almost directly proportional to atmospheric density, regardless of atmospheric composition (relative percentages of nitrogen, oxygen, water vapor, and other constituents). For microwaves, however, since water vapor has a much greater refractive effect than the natural gases, variation in water vapor content with altitude is such that it becomes the principal factor in the anomalous propagation of these waves.

The dependence of the index of refraction, n, on water-vapor pressure, e; temperature, T; and total atmospheric pressure, P; is best expressed by the empirical formula:*

$$(n-1)10^6 = \frac{79P}{T} + \frac{3.8 \times 10^5 e}{T^2} . \qquad (1)$$

In this formula, P and e are expressed in millibars (mb.), and T is the absolute temperature (273° + Centigrade temperature). Standard atmospheric pressure at sea level is 1,013 mb., and the pressure decreases about 3 mb. per 100-foot increase in altitude in the lower atmosphere.

The water-vapor content of the air is a function of temperature and relative humidity. At a temperature of 30° C. (86° F.) and a relative humidity of 50 per cent, the vapor pressure is about 21 mb. The relative effects of vapor pressure, temperature, and atmospheric pressure on the index of refraction of the air may be determined from Equation 1. It should be noted that the change in the refractive index resulting from a change of one millibar in vapor pressure is several times greater than for a unit change in temperature and 15 to 20 times greater than for a unit change in atmospheric pressure.

*Charles R. Burrows and Stephen S. Attwood, *Radio Wave Propagation*, The Academic Press, Inc. (New York), 1949. 548 pages.

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TRANSCRIBED TIME STUDIES

By W. D. JONES*

The need for eliminating "mechanical" errors from time and motion studies has long been recognized, as has the necessity for expanding the scope of the data recorded. The human-element limitations imposed by use of a stop watch have proved almost irremediable, and it was for this reason that an investigation was made, here at Georgia Tech, of the use of a transcription instrument (wire recorder) in time studies. From this research has come a procedure, described in the following article, which should prove of considerable value to those engaged in making and interpreting time studies.

The purpose of making most industrial time studies is the determination of "normal times" for elements of work, so that wage incentive standards may be established. The normal time for a given element of work may be defined as the time required for a qualified, trained employee to perform a given duty when using waste-free motions and working at a speed which is natural for the movement in question. Actually, however, since a given employee may be working either faster or slower than normal while being timed, it is necessary for the time-study man to rate the employee's productive effort and, later, to multiply the rating factor by the actual time taken, in order to approximate the normal time for the operation studied.

Besides the factor of accuracy, the value of the time study is largely dependent on the size of the elements of work which is timed. It is apparent that when a given operation is timed in its entirety, the time study obtained is useful only for determining the wage incentive rate for the one operation. When the individual elements which make up a given operation are timed separately, however, it is frequently possible to establish wage incentive standards for other total operations through the use of these predetermined elemental time values.

LIMITATIONS OF STOP-WATCH TIME STUDIES

Stop-watch time-study procedures place definite limitations on the refinement with which small elements of work may be timed and rated. After the cycle of an operation to be timed has been divided into individual work elements and after these elements are recorded in the proper order on the time-study observation sheet, the steps necessary when following the most popular stop-watch time-study procedure for timing and rating elements individually are as follows: (1) read the stop watch at the end of each element, (2) post the reading in the proper space on the time-study observation sheet, (3) closely observe the motion path and the rate of movement of the employee being timed and decide on an estimated rating of the employee's productive effort, and (4) post the rating in the proper space.

From the foregoing, it is readily apparent that a time-study man has little time in which to concentrate on the employee's productive effort when timing the useful standard data elements, which are generally less than 0.10 minute in duration. Moreover, the percentage of error in reading a decimal-minute stop watch graduated in one hundredths of a minute increases rapidly as elemental times decrease from 0.10 minute.

Moreover, the application of wage incentives to operations of a nonuniform nature has been inhibited because of the lack of a suitable time-study method. In attempting to make a stop-watch time study of a repair operation, for example, the time-study man must write down the description of each element of work while it is in progress, since this information cannot be predicted and recorded prior to the time study. The time required for describing the elements coupled with the time consumed in following the previously described time-study procedure usually render efforts fruitless when attempts are made to time

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the desired small work elements with a stop watch.

Wage incentive coverage of multiple activity operations has also been greatly restricted because of inadequate timing techniques. In this category are operations involving two or more employees working as a group on purely manual work, and jobs involving one or more employees working together at one or more machines. In the majority of these operations, things happen too rapidly for the time-study man to be able to record the necessary information when following usual stop-watch time-study procedures.

AN IMPROVED TIME-STUDY METHOD

In an attempt to remedy these problems, a transcribed time-study method (pictured in Figure 1) has recently been developed in the Rich Laboratories of Industrial Engineering at Georgia Tech. The principal feature of this technique involves the use of a standard, portable, magnetic wire-recorder which makes possible the recording by sound of the time-consuming, attention-distracting information which must be read from the stop watch and manually posted when following conventional stop-watch time-study practice. Use of this equipment makes possible the timing of short-cycle repetitive operations in their smallest detail, the timing of jobs of a nonuniform nature which requires that the descriptions of unpredictable elements be recorded during the time study, and the timing of multiple activity operations involving two or more employees working together or one or more employees working at one or more machines.

MAKING THE TRANSCRIBED TIME STUDY

In preparing for a time study with the wire recorder, the time-study man plugs the recorder extension into a power outlet, sets the dial to "recording," and engages the feed of the take-up drum. As the fine wire is drawn from the spool through the mag-

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Figure 1. Making a transcribed time study by use of a wire recorder.

FIELDS OF USE OF THE A-C NETWORK CALCULATOR

By HERBERT P. PETERS* and MARVIN O. RICHTER**

In the January, 1948, RESEARCH ENGINEER, Mr. Peters described in some detail the Georgia Tech A-C Network Calculator Laboratory and its potentialities for use in the solution of power networks. The a-c network calculator is a versatile instrument, however, and is also applicable to the solution of problems far afield from those of power systems. The following article presents a brief summary of available information on nonpower uses of the a-c network calculator.

The liberation of engineers from the drudgery of tedious mathematical calculations has been proceeding at a rapid pace during the past few years. The introduction of high speed digital computers, differential analyzers, analog computers, wind tunnels, hydraulic models, electrical network calculators, and numerous other devices has gone far in this direction; these apparatus permit rapid and accurate analyses of problems hitherto either impossible or, at best, difficult of solution.

The alternating-current (a-c) network calculator, such as the one installed at Georgia Tech, is one of the oldest examples of equipment for the solution of problems by model representation. This instrument was introduced in 1929 specifically for the solution of electrical networks of power systems. It consists of adjustable resistances, reactances, capacitances, transformers, and voltage sources so that it may exactly represent, on a miniature scale, an a-c power system.

In addition to its availability to power companies and others for use in the solution of their network problems, the Georgia Tech calculator is available to members of the Georgia Tech faculty and graduate students for use in research investigations. In order to present to those interested a resume of what has been done with electrical mod- literature search has been conducted by calculator laboratory personnel. The results of this search are set forth in this article.

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It is hoped that this article, by indicating what has already been accomplished, will stimulate in others ideas for the use of electrical analogs for the solution of their own problems.

HYDRAULICS

Fluid and electrical analogies are close but not exact. The conventional *electrical* system has constant pressure and variable rate of flow; the simple, single-conduit, continuous, steady, uniform *hydraulic* system has constant rate of flow and variable pressure. The electrical pressure drop (voltage drop) in a conductor varies directly as the rate of flow of the current, whereas the hydraulic pressure drop in a conductor (pipe) varies anywhere from the first power to the cube of the rate of flow. The pressure drop for the turbulent flow of water, for instance, is sometimes taken to vary as the 1.85 power of the rate of flow. R. S. Elberty[5] has discussed these fluid and electrical analogies.

To attempt to solve a hydraulic system with the use of the a-c network calculator, one must first set the system to be studied on the board. In this case, H may be considered analogous to V, Q to I, and K to R in the equations $H = KQ^x$ and $V = IR$, where H is hydraulic head; K is a constant; Q is quantity of fluid flow; x is a coefficient whose value, as discussed above, is variable but often taken as 1.85; and V, I, and R are the electrical quantities for voltage, current, and resistance. Since, as stated above, $H = KQ^x$ and $V = IR$, the electrical analog becomes $R = KQ^{x-1}$. From this last equation one can see that in order to set R on the calculator, it is first necessary to know Q, but one cannot know Q until he

has set R and read the flows in the individual pipes. It is therefore necessary to proceed by successive approximations, a method of solving hydraulic systems with the use of the calculator which has been discussed by T. R. Camp[1] and which saves little if any time when compared with such arithmetic methods as that of Hardy Cross.

In the fields of compressible and incompressible fluid flow, equivalent circuits have been developed[6] to represent three partial differential equations of mathematical physics under transient, sinusoidal, or steady-state conditions, thereby allowing their solution either by a network analyzer or by numerical and analytic circuit methods. In fluid dynamics these equations represent the steady potential flow of a compressible fluid when expressed in the hodograph plane or the general nonviscous flow of an incompressible fluid when expressed in the physical plane as space. In representing the flow of a compressible fluid in the physical space, the networks have variable units since the equations are nonlinear. The same equations and networks may be considered to represent static electromagnetic fields in current-carrying regions or in regions with stationary charges or poles. One of the equations may also represent the conduction of heat (or diffusion) in a nonisotropic medium, or it may represent the general wave equation.

All networks are expressed in curvilinear orthogonal coordinates to simplify the networks in case of curvilinear boundaries and to express three-dimensional problems with axial or other symmetry by means of a two-dimensional network. The coefficients of the equations are not scalars but elements of diagonal matrices, allowing special types of nonisotropic properties in the fields. All

Figure 1. The Georgia Tech A-C Network Calculator Laboratory, while created primarily for the study of power systems, can be used to represent any linear electrical network and can thus be employed in many studies in which an electrical analogue can be drawn.

coefficients may be constants or functions of the independent space variables, thereby allowing nonhomogeneous fields. The fields may contain multiple connected regions.

Most transient and steady-state equivalent circuits require only resistors, reactors, and capacitors, but some transient networks also require ideal transformers. The blocks into which space is divided may have arbitrary lengths in different directions. General nonisotropic fields and nonorthogonal reference frames require an extension of the present equivalent circuits. In general, the circuits may be used to check the consistency and accuracy of the results arrived at by other methods, approximate or exact. The unbalanced currents at the junctions (easily calculated) give a quantitative measure of the deviations from the correct answer.

In one article,[2] the flow function, Ψ, in the hodograph plane for compressible, potential flow was studied by use of an a-c network calculator. The circuit was first tested by calculating the current balance at the usual junction points of the network, using a distribution of Ψ values calculated from analytic solutions of the original differential equation. This procedure having shown the validity of the equivalent circuit, the network was then set up on an a-c network analyzer and was used to solve a whole field from given boundary conditions. The solution so obtained matched the differential analyzer solution of the same field and thus showed the feasibility of solving such field problems with present network-analyzer equipment.

ELASTIC STRUCTURES

Equivalent circuits have been developed[7] for one-, two-, and three-dimensional elastic structures that enable the solution of these structures by means of a network analyzer under steady small deformation and under forced or natural vibration. The elastic structure is assumed to consist of long, thin beams and rigid bodies having different elastic coefficients (tension and shear, bending and twist) along three perpendicular directions and interconnected into an arbitrary network either rigidly or by various constraints (pin joints, hinges, rollers, etc.) in any combination. The equivalent circuits of elastic structures have been numerically checked[9] for two known frames and have also been measured on the a-c network analyzer for the case of known impressed forces. In each case the measured values checked very satisfactorily with the calculated values, showing that existing analyzers can be used to good advantage to determine the forces and displacements in statically indeterminate structures.

FIELD EQUATIONS OF MAXWELL

An equivalent circuit has been developed[10] which represents the equations of Maxwell for an electromagnetic field containing conductors and bound charges. Both transient and sinusoidal field phenomena may now be studied by the network analyzer or by numerical and analytical circuit methods. Examples are radiation from antenna, propagation through wave guides and cavity resonators of arbitrary shapes, eddy currents in conductors, stresses in current-carrying structures, and other general problems in which moving charges either do not occur or, if they do, may be represented by equivalent dielectric constants, as in the case of small signal waves on stationary or moving space charges.

The equivalent circuits are developed for all curvilinear orthogonal reference frames to allow the solution, to any desired degree of accuracy, of special three-dimensional problems with axial or other symmetry by the use of only a two-dimensional network. The electromagnetic field may be nonhomogeneous, nonisotropic (of a special form), and may be divided into blocks of uneven length in different directions. The transient character of the circuit allows the variation of the frequency of the impressed quantities on the a-c network analyzer without varying the magnitude of the circuit impedances.

One set of two-dimensional networks, the transmission-line type, requires only resistors, reactors, and capacitors, while its dual set requires also ideal transformers in series with the inductive coils (in the transmission-line type of networks, the dual ideal transformers consist of impedanceless conductors). The three-dimensional network, being its own dual, requires both ideal transformer and impedanceless conductors. The use here of these two types of ideal

transformers plays a basic part in the identification of the scalar, vector, and Hertzian potentials and their duals on the equivalent circuit.

In one article,[12] studies are described in which equivalent circuits for the Maxwell field equations are set up on an a-c network analyzer. These circuits correspond to several simple electromagnetic cavities for which results are known. Comparisons made between the known theoretical results and field distributions measured from the equivalent circuits are used for verification of the equivalent circuits and for evaluation of the usefulness of present network analyzers in high-frequency field problems.

MATHEMATICS

The Schroedinger amplitude equation for one, two, and three independent variables in orthogonal curvilinear coordinate systems have been represented[8] by equivalent circuits. The network derived will allow the assumption of any arbitrary potential energy and may be solved within any desired degree of accuracy, either by an a-c network analyzer or by numerical and analytical circuit methods. It can be shown that by varying the impressed frequency on a network of inductors and capacitors (or by keeping the frequency constant and varying the capacitors), it is possible to find by measurement the eigenvalues, eigenfunctions, and the statistical mean of various operators belonging to the system represented. The electrical model may, of course, be replaced by an analogous mechanical model containing moving masses and springs.

Utilizing the type of circuit described in the preceding paragraph, tests[4] have been carried out on an a-c network analyzer. The tests reported included only one-dimensional circuits. Measurements were made of eigenvalues and eigenfunctions for the particular cases of the linear oscillator, the rectangular potential well, the double rectangular barrier, the single barrier, and the rigid rotator. These tests showed the circuit representation to be valid and to be adaptable to solution on the network analyzer.

In an article by G. Kron,[9] equivalent circuits are developed to represent some of the basic linear differential equations of mathemathical physics. The networks are valid for all orthogonal curvilinear coordinate systems and represent transient sinusoidal or static field phenomena. Besides the well-known Laplace and Poisson equations, the various models represent the general scalar-potential and vector-potential equations, the compressible fluid-flow equations in the hodograph plane, the electromagnetic field equations of Maxwell, the wave equations of Schroedinger, and the basic equations of the theory of elasticity. The networks are capable of solving initial-value, boundary-value, and characteristic-value problems, either by means of an analyzer or by numerical methods.

HEAT FLOW

The analytical solution of problems of thermal transients in thermal networks of any but the simplest character is very tedious. Also, experimental solutions of these problems with laboratory heat networks are by no means easy.

The solution of thermal problems by means of an electrical network depends upon the similarity in mathemathical form between Fourier's law of heat conduction and Ohm's law of electrical conduction. As a consequence of this similarity, there is an analogy between heat rate, thermal conductivity, and temperature gradient, on the one hand, and electrical current, electrical conductivity, and voltage gradient, on the other.

V. Paschkis[11] has designed an electrical model or calculator to solve heat flow problems by use of the above analogy. In his model he used resistors and capacitors with direct current, and has done much work in this field by use of his calculator.

The a-c network calculator does not have direct current power available, and, even if it did, the values of resistance and capacitance used by Paschkis are far greater than any similar values which are available on an a-c network calculator. It is impractical, therefore, to attempt to solve heat flow

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VISUAL SCREENING DEVICES

By JOSEPH E. MOORE*

Vision, besides being a prized personal possession, is of economic significance to industry, which employs individuals in many positions in which good vision is vital. The following article presents an analysis of instruments and tests for determining the visual traits of industrial workers.

Human vision varies greatly from individual to individual. Moreover, visual performance within the same individual changes with age, especially after the age of 40. Therefore, the importance of eyesight testing of industrial workers cannot be stressed too strongly, both for the screening of applicants and for providing better eye care for those who are already employed.[5] The fact that this need is now widely recognized by employers may readily be seen from the number of research articles which have been published recently on this subject: some 79 per cent of all the articles touching on vision and its industrial aspects have appeared during the last ten years.[19]

From the employer's point of view, good vision of his workers has paid dividends through better production. Moreover, employers have also had to consider compensation laws which make it almost essential to ascertain the level of visual skills possessed by a new employee, so that plant records will, if needed, provide a factual basis for answering damage suits based on visual loss.

On the employee's side of the question of better visual screening, it may be pointed out that present industrial practices call for much prolonged observation work under artificial light. Workers have to focus their attention on small objects for long periods of time, and in many different tasks. It is certainly of importance to the employee, then, to avoid eyestrain or permanent damage to the eyesight both by more intelligent eye care and through proper interpretation of improved visual screening methods.

NEED FOR SCREENING TESTS

Vision, as mentioned earlier, changes with age. A worker whose vision is adequate for fine precision work at one time in his life may be unable to perform these tasks satisfactorily when he has reached another age level. Moreover, the extent of visual defects appears to be far greater than most employers have previously thought.

A recent survey of 16,332 industrial employees in several plants revealed that serious visual defects were present in 15 to 38 per cent of those surveyed.[15] These figures, although large, were not as serious as those reported by Tiffin,[22] who stated that "the visual skills necessary for safety, high production, and good quality of work are lacking in from 10 to 50 per cent of industrial employees." This statement was based on statistical research involving several thousand employees in more than 50 industrial plants.

A similar study of 1,750,000 workers in Great Britain, which supports the same conclusion, found that 40 per cent of the workers' visions could be improved from the standpoint of production. Five to eight per cent of all workers had one or more severe eye deficiencies.[17]

Serious eye injuries among workers are even more startling. Snell[15] states, "There are in the United States 8,000 industrially blind employees and 80,000 employees blind in one eye because of industrial accidents. There are 300,000 compensable eye accidents yearly taking place. These do not include trivial accidents resulting from uncomplicated injuries to the eye."

It is surprising to find that conditions are not markedly improved even when one looks at a specific industry which requires a high level of visual ability. A visual screening of 800 employees on the Nickel Plate Railroad revealed that slightly over 15 per cent of the men were in serious need of visual correction.[7]

The above-mentioned studies indicate that visual defects and even serious eye injuries

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are more prevalent than most employers realize. These deficiencies in human vision call for early identification and, in many cases, referrals to specialists who furnish corrections, eye care, and/or treatment.[10]

VISION—SOME ABC'S

Before considering the various instruments for visual screening of job applicants and workers on the job, it might be well to review briefly (and perhaps even with oversimplification) some of the basic facts about human vision. There are two main variables in seeing. First, there is the visual mechanism itself, which involves such factors as the curvature of the eyeball and the series of highly complicated muscles and muscular adjustments which take place both within and without the eyeball. The extremely delicate muscles within the eyeball strive to make the visual image fall sharply and clearly outlined on a highly specialized spot. Each eye, when focused on an object, it turned and held in place by six large muscles attached to the outside surface. There are many other adjustments necessary to seeing, but mention of the above should suffice to indicate that seeing is a very complex behavior.

The second chief variable in one's ability to see is the conditions which surround the eye. The general health and physical condition of the individual are two of the factors here. Other, more external factors are illumination, distance, glare, movement, dust, moisture content of the air, background against which objects are seen, etc. These are not all of the variables, but they suffice to indicate that, even if one has perfect eyes, other conditions can make them perform poorly.

VISUAL SCREENING INSTRUMENTS

The need for business and industry to have quick, simple-to-administer visual screening devices for accurately selecting and placing workers has long since come to the attention of instrument makers. These devices which will be discussed below were selected from the many developed because of their objective and scientific natures. In selecting these for discussion, an attempt was made to "cull out" techniques whose descriptions failed to present quantitative data to support their claims. The list presented here is not an exhaustive one by any means, but it is at least a representative one.

There are five widely used visual screening devices on the market at the present time, as pictured in Figure 1. These include: (1) tests for color-blindness (American Optical Company, Southbridge, Massachusetts), (2) Snellen Charts (American Optical Company), (3) the Ortho-Rater (manufactured by Bausch and Lomb Optical Company, Rochester, New York), (4) the Sight Screener (manufactured by the American Optical Company), and (5) the Telebinocular (manufactured by Keystone View Company, Meadville, Pennsylvania).

The last three instruments include a color-blindness test as part of their battery of tests, and are similar in some respects. For example, they all employ a constant light source, and each one utilizes lenses to compensate for near distance of 13 inches, or at least for far point focus of 20 feet. Each instrument tests each eye separately as well as both together. These instruments enable measurement of muscular balance, depth perception, and several other visual skills.

It now seems timely to take up each type of instrument or test, separately, and thus to discuss it in some detail.

DETERMINATION OF COLOR-BLINDNESS

No adequate figures are at hand on the extend of color-blindness in the American population. However, Neubert[13] tested 40,380 British men and found that 5.5 per cent were color-blind as measured by the Ishihara color plates.

Tiffin and Kuhn,[23] in 1942, used a simple four-item red-and-green color discrimination test on 7,000 employees. They reported that 44.7 per cent of the employees had difficulty discriminating colors on this test but made no estimate of the percentage which should be classed as color-blind. Their data indicated, moreover, that color vision diminishes markedly with age. They found that 74 per cent of the workers between the age of 20 and 25 passed the color vision test, compared to only 32 per cent of the workers over age 55. These results, however, are in

conflict with the findings of Boice, Tinker, and Peterson,[2] who could find no evidence that color-blindness increased with age.

In another study of 2,083 industrial workers, Strebel[18] reports that five per cent of the men had very poor color vision, whereas only two per cent of the women tested had very poor color vision.

Tests of color vision are among the oldest screening devices employed by business and industry. These tests are supposed to screen out those individuals who have difficulty in seeing and picking out different colors, particularly red and green.

A review of some of the investigations reported might prove helpful in evaluating present instruments. Chapanis[5] tried five tests of color vision and reported that the Bostroem-Kugelberg device was by far the best all-around test of color deficiency of those he investigated. In another study, the Ishihara Test for color-blindness was severely criticized by Hardy, Rand, and Rittler.[6] These investigators concluded their study by stating that the results obtained from the test depend to a great extent on the illuminant used. They warned that use of this test gave neither qualitative (type of defect) nor quantitative (extent of defect) diagnosis, and that its use could give a wrong diagnosis.

In a study of 200 men using the Pseudo Isochromatic, Ishihara, and the Jensen tests for color-blindness, the results obtained showed good agreement only between the first two tests.[4]

One personnel man has described his industrial experience with the Ishihara color-blindness test. He points out different areas of weaknesses in applying the test and interpreting the results from it.[11]

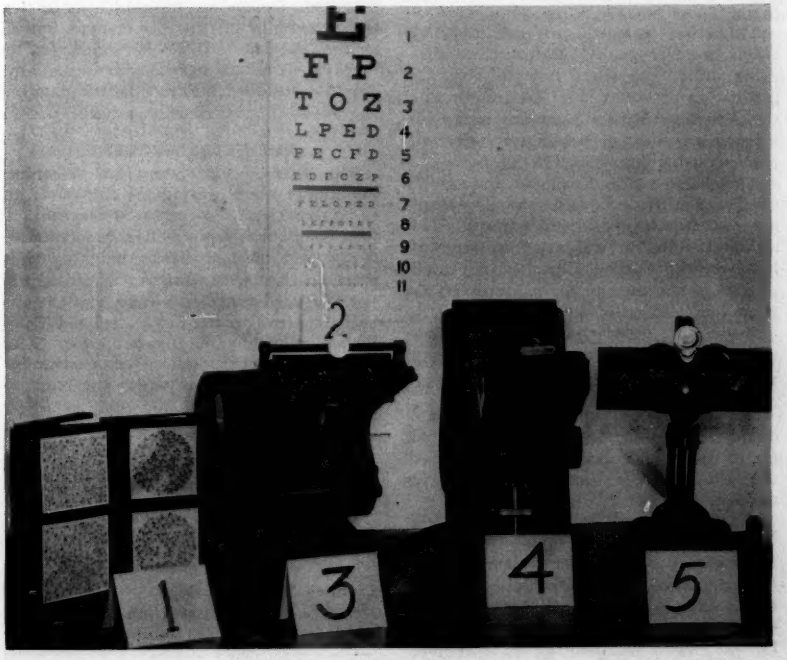

Figure 1. Visual screening devices.

SNELLEN CHART

The Snellen Chart is one of the most widely used tests of visual acuity. This test has been and remains today a professional, clinical means for determining how well a person can see and read block letters of a particular size and design. The test was constructed to measure acuity at a distance of 20 feet. A person's ability (without glasses) to read this chart, starting with the largest letters and coming down to the smallest he can make out, determines his acuity score. This score is stated in the form of a fraction, the numerator being a constant which represents the distance he stands from the test and the denominator representing the variation in size and number of letters read. For example, a visual acuity of 20/10 would mean that a person can see letters so small that the "average" person with "standard vision" would need to get within ten feet of the chart to see them.

This chart measures only one aspect of vision, however—acuity. Moreover, in measuring acuity the chart fails to give any graduation of visual loss. To remedy this, the American Medical Association has developed a percentage system for converting Snellen rating into visual loss.

The Snellen Chart affords industry a quick and fairly dependable basis for screening out workers with substandard visual acuity. If illiterate workers are to be tested, however, the Snellen Chart in its standardized form cannot be used. Moreover, the chart has been criticized because it fails to measure such other visual factors as muscular balance and depth perception.

THE ORTHO-RATER

The Ortho-Rater appears to have more quantitative studies back of it[9, 10, 20, 21] than either the Sight Screener or the Telebinocular. It has been used in numerous industries, as follows.

Hosiery Manufacturing

Employees of a hosiery manufacturing company who met visual standards on the Ortho-Rater were decidedly better producers. Eighty-three per cent of the best full-fashion loopers who met the visual requirement had 30 per cent less spoilage than those loopers who failed to meet the company's visual standard.[24]

Textiles

Sixty-eight per cent of all winder tenders who failed to meet the visual standard of the Ortho-Rater had low earnings. Among the winder tenders who met the standard, 65 per cent had high earnings.[14]

Film Company

The use of the Ortho-Rater in the selection of new portrait hand examiners gave an 11 per cent increase in the number of better and average workers selected, and an 11 per cent decrease in the number of poor workers.[8]

THE SIGHT SCREENER

The Sight Screener is somewhat restricted in its use in that the American Optical Company requires any plant desiring to use it to have the services of a member of the opthalmic profession. It ranks next to the Ortho-Rater in the number of quantitative studies reported on it.[9, 10, 20, 21] However, to date, the writer has been unable to find any objective studies reporting research data on the use of this instrument in industry.

THE TELEBINOCULAR

The Telebinocular is a visual screening instrument which was among the very first to be developed. Its early performance left something to be desired in one or two respects, and an extensive redesigning program on the instrument was instituted. It is to be regretted that so few studies have been reported on the newly designed Telebinocular up to the present time. The following visual studies are reported under the type of industry in which the research was done.

Textile

Inspectors of cones of rayon thread who scored better on the Telebinocular for near acuity had better production records than their co-workers whose near vision was below average.[1]

Clothing Manufacturing

Thirty-eight applicants out of 718, or 5.3 per cent, were refused employment because

Continued on Page 21

DIGESTS OF GRADUATE THESES

ELECTRICAL ENGINEERING

1948-1949

The following digests represent summaries of theses submitted during 1948-1949 in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering. This is the third in a series of articles designed to present data on the graduate theses submitted last year to the various schools of the Georgia Institute of Technology.

Davies Powell Anderson. *Negative Resistance Characteristics and Use of Crystal Diodes.* Faculty advisor: Professor M. A. Honnell.

A study was directed toward an examination of the characteristics of the germanium crystal diode, its applications in the negative resistance region, and its negative resistance properties.

Methods for obtaining the characteristic curves of crystal diodes and the merits and limitations of these methods are presented. The practical application of the negative resistance characteristics of the germanium diode in a sine-wave oscillator and in a relaxation oscillator is discussed, as are the connection and adjustment of circuit parameters in the oscillator circuits. Photographs of the resultant waveforms generated by the oscillators are presented. A mathematical analysis of the sine-wave oscillator is given which confirms experimental results.

This investigation shows that the crystal diode employed as a negative resistance in a suitable circuit can produce oscillations of good stability. *M.A.H.*

Morris David Prince. *Resolution as a Function of the Band-Width in a Television System.* Faculty advisor: Professor M. A. Honnell.

Results are presented of an investigation of the horizontal resolution of a television system as affected by the bandwidth of the system. Four distinct bandwidths achieved by suitably designed shunt-compensated coupling networks were used. The corresponding resolution was measured and evaluated, under these four bandwidth conditions, by the presentation of test charts to a number of observers.

It is shown experimentally that the resolution corresponding to narrow bandwidths is greater than would be expected if the resolution were directly proportional to the bandwidth. These experimental results are substantiated by a discussion concerning the manner in which the sensory system responds to the image reproduced by the television system.

The effect of restricting the bandwidth is illustrated by photographs of various types of subject matter televised under the four bandwidth conditions. Some additional topics of interest are mentioned, and the direction for further research is indicated. *M.A.H.*

Harry Wilkerson Ragsdale. *An Investigation of Transformer-Coupled Push-Pull Audio Amplifiers.* Faculty advisor: Professor M. A. Honnell.

This thesis presents a study of the frequency response of transformer-coupled, push-pull audio amplifiers as affected by tube and winding capacitances under normal and neutralized conditions.

It was found that a simple form of neutralization when applied to a properly designed, transformer-coupled, push-pull audio amplifier using high-quality component parts does not greatly improve the over-all frequently response and phase characteristics of the amplifier.

Furthermore, it was found that additional peaks are present in the over-all frequency-response characteristics of transformer-coupled audio amplifiers that are not shown on frequency-response curves which are representative of the transformer-coupled amplifiers described in the standard literature. An equivalent circuit for an interstage transformer including these additional resonances was synthesized by making appropriate impedance measurements upon the transformer. The calculated zeros and poles of impedance are in close agreement with the measured zeros and poles, as shown on plots

of the experimentally determined impedance locii. *M.A.H.*

William B. Wrigley. *A Mathematical Treatment of Nonlinear Oscillations.* Faculty advisor: Dr. W. A. Edson.

Network theory has recently been greatly strengthened by use of relationships between the time domain and the associated complex frequency domain. This investigation showed that problems involving sustained oscillations in nonlinear networks may be treated to advantage by extending the definitions of fixed singularities in the complex frequency domain to include singularities which are permitted to move about in the plane as a function of time. Previous work on nonlinear theory provided a basis for this treatment, which involves the concept of moving roots.

A new form of envelope and angle function for expressing system responses was proposed. The motion of the roots was determined by examining a solution to a particular problem of nonlinear oscillation. From this study it appears that the general mathematical form of the moving root concept provides an alternative to the Fourier and Laplace representations of real functions. *W.A.E.*

MICROWAVES

Continued from Page 4

In regions of barometric highs, where warm, dry air often subsides slowly over a humid surface layer, vapor-pressure lapses as great as 8 mb. per 100 feet have been observed. In such subsidence, the temperature may also increase rapidly with altitude. By referring again to Equation 1 it may be seen that this combination of moisture lapse and temperature increase with altitude will result in a relatively large decrease in refractive index.

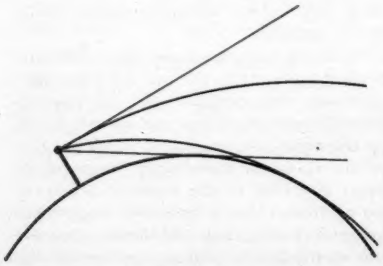

Figure 2. Curvature of rays in the atmosphere for a vertical gradient of index of refraction of -2.4×10^{-8} per foot, also showing extension of radar horizon.

Figure 3. Curvature of rays in the atmosphere for a vertical gradient of refractive index of (A) -4.8×10^{-8} per foot and (B) -10×10^{-8} per foot (here, showing surface trapping of microwaves).

Refractive index changes of the same order of magnitude may also be associated with other types of atmospheric stratification. For example, on nights when the skies are clear and there is little wind, radiation from the earth cools its surface to a considerably lower temperature than that of the adjacent layer of air. In the resulting temperature inversion, the index of refraction decreases rapidly with altitude. If moisture lapse is associated with such a temperature inversion, the effects on propagation are even more pronounced.

An atmosphere is termed "standard"* if the change of refractive index with altitude is -1.2×10^{-8} per foot. This small vertical gradient of refractive index produces a curvature of the rays about one fourth as great as the curvature of the earth. Figure 2 illustrates the effects of a vertical gradient of -2.4×10^{-8} per foot. The ray paths in the lower atmosphere are curved, and the radio (or radar) horizon is extended as a result of the downward curvature of the rays. For a refractive index gradient of -4.8×10^{-8} per foot the curvature of the rays equals the curvature of the earth, as shown in Figure 3. For still greater negative gradients of the refractive index,

*This definition of a standard atmosphere is based on the average conditions in a well-mixed atmosphere in the temperate zones.

microwaves may be trapped in a surface layer. This effect, called surface trapping or duct propagation, is also illustrated in Figure 3. Moisture lapses and/or temperature increases with altitude are frequently great enough to produce refractive index gradients of these magnitudes.

PATHS OF PROPAGATION

Many of the Georgia Tech propagation studies were made over a path of propagation between a penthouse on the building of the School of Physics (elevation, 1,040 feet) and the peak of Mt. Oglethorpe (located, at an altitude of approximately 3,300 feet, about 50 miles north of Atlanta); a profile of this path is shown in Figure 4.* Three ways in which energy may travel from the transmitters on the Physics Building to the receivers on Mt. Oglethorpe are illustrated by the ray paths in this figure. The top ray represents reflection (or internal refraction) by a subsidence inversion layer in which the index of refraction has decreased sufficiently to bend the ray downward. It appears probable that the particular types of atmospheric stratification below the transmitter level may cause similar reflections, so that the lowest ray might be considered as either reflection from the earth or from a nonstandard atmospheric layer. Because of interference effects, multiple-path transmission, as illustrated by the three full-line rays, could cause large variations in the amplitude of the received signal.

*The height scale shown is magnified in comparison with the radius of the earth and horizontal distance. This was necessary in order to show terrain irregularities, heights of transmitter and receivers, etc.

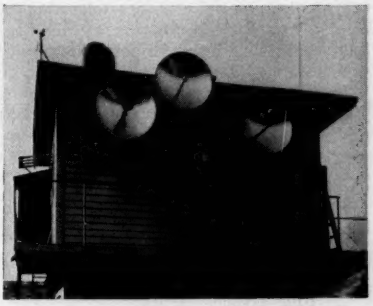

Figure 5. Transmitting antennas atop the Georgia Tech Physics Building.

When the Georgia Tech-Mt. Oglethorpe experiments were completed, the receivers

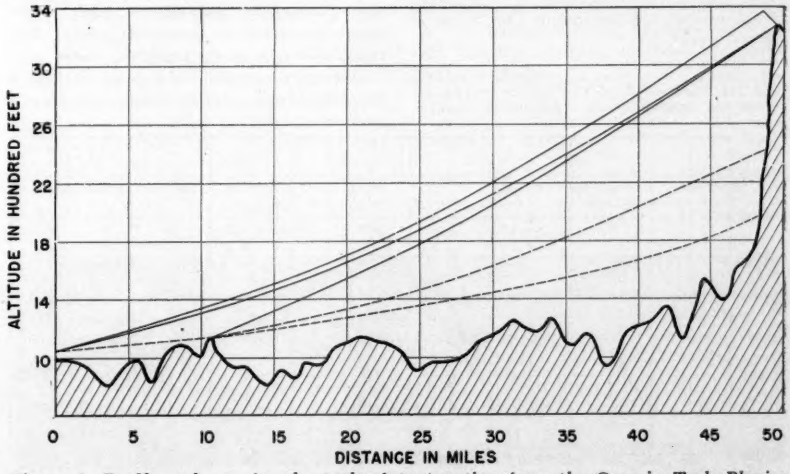

Figure 4. Profile and rays for the path of propagation from the Georgia Tech Physics Building to Mt. Oglethorpe. Dotted lines show ray paths for standard (upper) and superrefractive (lower) conditions.

were moved to a lower site (elevation of 2,040 ft.) on Rich Mountain. The broken-line curves in Figure 4 show that under standard conditions the Rich Mountain site would lie in the diffraction zone (below the horizon) but that superrefractive conditions would have the effect of elevating the receivers to a point above the horizon.

TRANSMITTING AND RECEIVING STATIONS

Figure 5 shows the three transmitting antennas mounted on the penthouse of the Physics Building. Each of the antennas has a radiating element mounted at the focus of a dish-reflector which is 40 inches in diameter. The reflectors serve as concave mirrors which concentrate the microwave radiation into narrow beams and thus magnify the signals transmitted to the receivers.

The receiving antennas were mounted on a mobile van which could be moved to various sites on the mountains. Two of the antennas on this receiver van are pictured on the cover of this issue, the picture having been taken during one of the Mt. Oglethorpe operations.* The receiver van housed radio receiving equipment, recording instruments, etc., and also served as living quarters for the two-man operating crew during the experimental operations, which usually ran continuously for a period of two weeks.

*It may be of interest to note that the monument in the background of this picture marks the southern terminus of the Appalachain Trail.

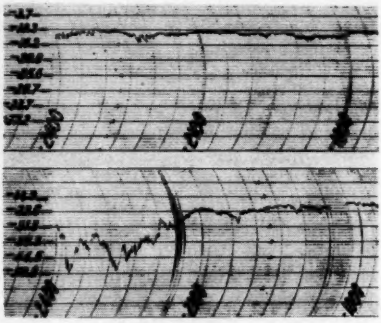

Figure 7. Signal strength (in db.) versus time at 2,860 mc. (top) and 9,400 mc. (bottom), showing attenuation of signal by heavy rain.

METEOROLOGICAL MEASUREMENTS

Atmospheric conditions along the path of propagation were explored by means of atmospheric sounding instruments for the measurement of pressure, temperature, and humidity. Several methods were employed in the collection of these atmospheric sounding data. A special plane furnished by the Army Air Force made two or more flights daily along the propagation path, when weather conditions permitted. Wet- and dry-bulb temperatures and atmospheric pressure were recorded in the plane at height intervals of about 100 feet from near ground

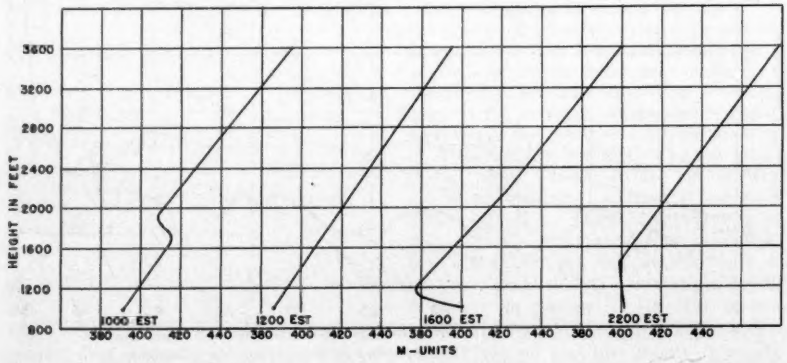

Figure 6. Modified index of refraction (M) as a function of altitude on August 30, 1948.

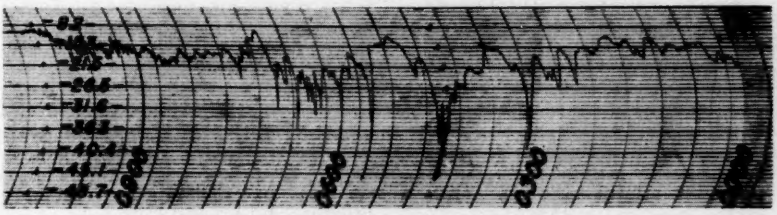

Figure 8. Signal strength (in db.) versus time at 2,860 mc., showing deep fading resulting from radiation cooling and ground fog.

level to altitudes of 5,000 feet or more. The wet- and dry-bulb temperatures were measured with a psychrometer attached to the undercarriage of the plane.

Balloon soundings were also made at a meteorological site near Roswell. Two types of instruments were utilized in these balloon soundings. In the earlier experiments, ceramic temperature elements (thermistors) were employed. These thermistors were mounted in a radiation shield, which was attached to the balloon, and were connected to recording instruments on the ground by a light electrical cable. In later experiments, a camera meteorograph was used as the balloon sounding instrument, and the sounding data were recorded photographically.

In addition to the data obtained directly by operational personnel, radiosonde data and other weather information were supplied by the Atlanta Weather Bureau.

The atmospheric sounding data were used to calculate the index of refraction from Equation 1. The index of refraction distribution in the atmosphere at the time of the sounding was then recorded as a plot of refractive index versus height. Figure 6 shows some of the results plotted in the customary form as M-curves. The modified index of refraction, M, is defined by

$$M = (n - 1 + \frac{h}{a})10^6 \qquad (2)$$

where h = height above mean sea level and a = radius of the earth. One reason for the use of M rather than n is that this permits expression of the refractive properties of the atmosphere in whole numbers rather than in the minute fractions given by $(n - 1)$,* and it is more convenient to plot data in terms of the whole numbers. An M-curve is a plot of M versus height. When M increases with altitude (positive M-gradient) the rays curve upward on a flat-earth diagram, and when M decreases with altitude the rays curve downward on such a diagram. When M does not vary with height, the rays are parallel to the earth's surface.

*It should be noted that the basic reason for expressing M in terms of $(n - 1 + \frac{h}{a})$ rather than $(n - 1)$ is that the rate of change of the former with altitude represents the curvature of a ray relative to the earth's surface, and thus permits rays to be plotted on "flat earth" diagrams.

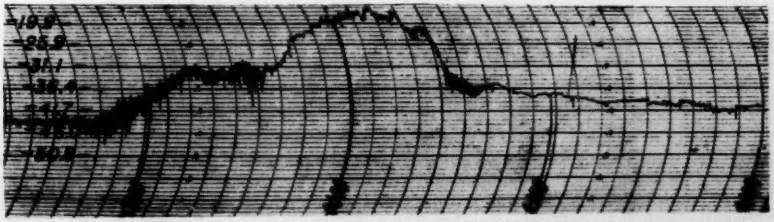

Figure 9. Signal strength (in db.) versus time at 9,400 mc., showing reception below the horizon under superrefracting conditions.

SIGNAL STRENGTH VARIATIONS

In 1947 and 1948, large quantities of signal strength data were collected in a series of microwave propagation measurements over the aforementioned paths of approximately 50 miles between the Georgia Tech Physics Building and receiver sites in the mountains of North Georgia. Continuous recordings of received signal strength were made for each of the three microwave frequencies during many extended periods of operation which usually lasted approximately two weeks each. Typical results obtained under conditions of anomalous propagation, or when nonstandard atmospheric conditions existed, are presented in Figures 7 through 9.

On July 10, 1948, there were heavy rain showers along the path from Georgia Tech to Mt. Oglethorpe between the hours of 9:00 P. M. (2100) and 12:00 P. M. (2400). The signal strength records at 2,860 and 9,400 megacycles during the last six hours of the day are shown in Figure 7. Incidentally, it is customary to record signal strength in decibels (db.) relative to a reference level of one milliwatt,* where decreases of 10, 20, and 30 db. correspond to reductions of received power by 10, 100, and 1,000 times. Figure 7 shows that the 9,400-mc. signal was attenuated greatly during the period of heavy rainfall, but that there was relatively little effect on the 2,860-mc. signal. The maximum attenuation at 9,400 mc. was about 30 db., corresponding to a signal level about one thousandth as great as the value immediately preceding the rain. On the other hand, the received signal at 2,860 mc. was remarkably steady, with maximum variations of only 100 or 200 per cent.

On August 8, 1948, between midnight (0000) and 10:00 A. M. (1000), during another period of operation over the Georgia Tech-Mt. Oglethorpe path, the received signals were of a rapidly fluctuating type, characterized by deep fades for the 2,860-mc. frequency, as illustrated in Figure 8. The signal strength records at 1,310 mc. and 9,400 mc. were of the same general type, except that the rapidity of fluctuation increased with frequency. The depth of fading was also somewhat more pronounced at the higher frequencies. The night of August 8, 1948, was clear and calm (cloudless skies and little wind). As a result, there was excessive radiation cooling of the earth's surface, with the resultant formation of a surface stratified layer in which the index of refraction decreased rapidly with altitude. This condition was followed by radiation fog along portions of the path where the air was cooled below the dew point. Large signal strength fluctuations have been observed on many occasions under these conditions. It appears that the fluctuations are closely associated with nonstandard refraction in the surface atmospheric layer. The deep fades indicate that energy is transmitted to the receiver along two or more paths through the atmosphere. Atmospheric inhomogeneities along the path are to be expected as a result of irregular terrain features and tree coverage. Consequently, it appears highly probable that under these conditions energy will reach the receivers via more than one path. Statistical analysis of the signal strength fluctuations lends support to this theory.

The pronounced effect of nonstandard atmospheric refraction on the propagation of microwaves is shown most conclusively by the signal strength record presented in Figure 9, which was recorded during one of the periods of propagation over the Georgia Tech-Tolen Mountain path. Under standard atmospheric conditions the receiver truck on Tolen Mountain was several hundred feet below the radar horizon, and the received signal was approximately 25 decibels below its free space value. During the early morning of October 17, 1948, however, as shown in Figure 9, the received signal increased about 300 times (about 25 db.). This illustrates the effect of superrefraction in bending the rays around the surface of the earth.

The examples of signal strength records shown in Figures 7 through 9 were chosen to illustrate the marked effects of meteorological conditions on microwave propagation through the lower atmosphere. Signal variations of the same general types and magnitudes have been recorded frequently during the Georgia Tech experiments. In the absence of rain, the large signal fluctua-

*The abbreviation dbm. is commonly used for decibels relative to one milliwatt.

tions usually occur on calm, clear nights when conditions are favorable for surface stratifications resulting from temperature inversions and water vapor lapses. The most pronounced fades are generally associated with radiation fog in the early hours of the morning. On the other hand, the signal is usually remarkably steady from about 9:00 A. M. until nightfall, when convection currents (resulting from solar radiation) keep the atmosphere thoroughly mixed, so that the index of refraction distribution is approximately standard. Steady signals are also associated with overcast skies which prevent loss of heat by radiation from the earth's surface.

The large masses of data recorded for each of the three microwave frequencies in more than 3,000 hours of operation are being analyzed statistically in an attempt to correlate signal strength characteristics with particular types of atmospheric stratification. Definite correlations have been found, and further studies are in progress to establish more firmly the basic physical mechanisms responsible for the signal variations. The data are also being summarized in the form of per cent-time curves, which show the fractions of total operating time that the signal strength was above or below various levels. It is believed that these results may be of use in evaluating the probable performance of microwave systems, such as those used in long-distance telephone and television transmission for similar paths of propagation.

ACKNOWLEDGMENTS

The author wishes to acknowledge particularly the contributions to this study of Dr. F. E. Lowance, who served as project director for more than two years; R. A. Martin, who was in charge of experimental operations; and the many others who worked on this project.

VISUAL SCREENING

Continued from Page 14

of impaired vision. The use of visual tests plus dexterity testing resulted in a saving of $80.65 on each trainee employed during 1947, because of lowered training costs.[12]

SUMMARY AND CONCLUSIONS

The value to industry of visual screening instruments has so far been the subject of much more salesmanship than carefully controlled investigations. With this word of caution in mind, the following conclusions may be drawn:

1. Visual defects are very numerous among employees of the types of industries studied. Poor vision appears to increase with age.

2. Tests for color-blindness vary greatly in effectiveness for screening out employees with poor color performance.

3. Present devices for screening general visual skills appear useful. The value of these instruments has, however, been presented all too often in terms of broad claims rather than objective data.

4. The encouraging reports of substantial savings from reduced spoilage, labor turnover, absenteeism, accident reduction, etc., need to be accepted with great caution.

5. More and better-controlled studies in industry are needed before one can assess the usefulness of present visual screening instruments.

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TIME STUDIES

Continued from Page 6

netic recording head and onto the take-up drum at uniform speed, the time-study man talks into the microphone and magnetically transcribes on the recording wire relevant information such as his name, the time of day, the employee's clock number and name, comments regarding the job and the work place, average number of parts in trays and tote-boxes, etc.

The next step, when preparing to time an employee on an operation having repetitive, identical cycles, is to determine the most desirable elemental break-down from the standpoint of eventual standard data requirements. A description of each element and its end point is then recorded by speaking into the microphone. After the elemental end points are well in mind, the time-study man is ready to begin the actual timing of the employee.

In timing the employee, the time-study man merely taps the back of the microphone at the end of each element, using a tapper worn on the forefinger of the hand holding the microphone. Each end point tap produces a sharp sound which is later identified (on playing back the recording) by the simultaneous sharp tap sound and an abrupt flash of the volume-control neon lamp. The durations of the individual elemental occasions are later measured by converting into time the distance between successive end point taps on the recorded wire.

Comments pertaining to reasons for wide variations in elemental times are recorded while the time study is in progress, merely by speaking into the microphone. Also, foreign elements and delays are timed and described without interference with the timing of regular work elements.

As the time-study man closely observes the employee's motion pattern, he estimates and records estimates of the employee's productive effort. When the employee's productive effort varies within the cycle, elemental occasions are rated individually. A rating of 90 per cent is recorded as "nine," 110 per cent as "eleven" and 125 per cent as "twelve five." Individual cycles rather than elemental occasions are rated when an employee's productive effort does not vary significantly within the cycle.

The timing of nonuniform work such as maintenance and salvage is basically the same as that described above. Since the nature and sequence of the work elements cannot be predicted and recorded before the actual timing, however, this information must be recorded as the actual timing progresses. Unlike in stop-watch time studies however, this does not necessitate that the time-study man divert his attention from the employee being timed.

The timing of multiple activity operations involving two or more employees working together or one or more employees working at one or more machines is somewhat different from the regular timing technique. When it is desired to differentiate between two employees being timed simultaneously, for example, different-sounding end point signals must be used for the timing of each

Figure 2. Close-up of wire recorder as adapted for time-study playback.

employee. In such cases, it is generally desirable to have an individual time-study man for each employee. These time-study men work independently of each other, each having a separate microphone, but each recording on the same wire. Any recording other than elemental end point signals, of course, must be limited to prevent simultaneous recording.

"PLAYING BACK" THE TIME STUDY

After the actual timing has been completed, the recording is rewound on the spool and then played back. Since the usual spool of wire provides for one hour's recording, several recorded time studies can be made in succession if desired. After the recorded information is taken from the wire, other recordings can be made on the same wire, since any existing recording on the wire is automatically demagnetized or "erased" by the recording head as a new recording is made. If desired, however, a recorded time study may be preserved permanently by storing the spool of wire which contains it.

In use, the spool containing the recorded time study is played back for the purpose of measuring the time intervals between the recorded end point signals, these elemental times and the recorded elemental descriptions being posted on the time-study sheet. The measuring apparatus (Figure 2) consists of a standard revolution counter equipped with a pulley, a take-up drum pulley, and a spring belt, quickly assembled to the wire recorder. The dial is turned to "listen," and the feed of the take-up drum is engaged. As the wire is drawn from the spool and through the recording head by the take-up drum, the pulley on the take-up drum drives the pulley on the counter by means of the spring belt. The ratio between the two pulleys is such that one thousand units pass the counter window during each minute of playback. This permits measuring elements in terms of one thousandths of a minute.

After the recorded information pertaining to the operator, the work place, and the elements of the operation has been played back and posted on the time-study sheet, the durations of the elemental occasions are measured. The elemental times are measured as follows: (1) the take-up drum feed is disengaged just as the elemental end point tap is heard and the flash of the neon volume indicator lamp is observed, (2) the counter is read and the time reading and rating are posted on the time-study sheet, (3) the counter is zeroed by means of its reset wing nut, (4) the take-up drum feed is engaged, and (5) the analyst listens for the rating and end point tap of the next element.

ADVANTAGES OF TRANSCRIBED TIME STUDIES

In addition to the matter of precision, the recorded time-study technique has certain intangible advantages over the conventional stop-watch time-study method. First, because a few accurately timed and carefully rated cycles are generally more reliable than a great number of poorly timed and rated cycles, the transcribed time-study technique significantly reduces the duration of the actual timing. Consequently, any interruption in production because of the time study is also reduced. Secondly, in replacing the often-dreaded stop watch with the microphone, the time-study man alleviates unfavorable employee reactions to time study. Finally, the transcribed time-study technique tends to insure against bias of the time-study man when timing and rating the employee. Since the times and ratings are not posted on the time-study sheet until after the study is completed, the time-study man cannot be influenced by previous decisions.

It might be well to summarize the relevant tangible differences between the transcribed time-study method and the conventional decimal-minute, stop-watch time-study method. First, the wire recorder makes it possible to measure elemental times to the nearest one thousandth of a minute, while the decimal stop watch permits reading only to the nearest one hundredth of a minute. This means that small elements of work such as "get and assemble" and "get and use" can be individually and accurately timed for standard data purposes. Secondly, when recording orally through the microphone, the time-study man can keep his attention on the employee during 100 per cent of the time study, rather than only for a fraction of the time as is generally the case when making stop-watch time studies. Consequently, the time-study man can more accurately rate the operator's productive effort, can observe and record the effects of quality variations and foreign elements, and, in the case of operations having non-uniform cycles, can accurately record elemental descriptions while the time study is in progress. Finally, by replacing the reading and writing of the stop-watch time-study procedure with a sound transcription, the transcribed time-study technique greatly simplifies the simultaneous timing of several activities.

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NETWORK CALCULATOR

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problems on present a-c network calculators by use of the method set forth by Paschkis.

* * *

This article has covered only a few of the fields in which studies have already been conducted; the a-c network calculator is applicable for use in many more. It is anticipated that some of these nonpower-system studies will shortly be performed in the Georgia Tech A-C Network Calculator Laboratory, which has already participated in a few dealing with fluid flow.

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WHAT IS RESEARCH?

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or, more to the point, "studious inquiry or examination; specifically and usually, critical and exhaustive investigation or experimentation having for its aim the discovery of new facts and their correct interpretation, the revision of accepted conclusions, theories, or laws in the light of newly discovered facts, or the practical applications of such new or revised conclusions, etc." While this definition may not seem satisfactory to all, it still is testimony to the fact that research is not the exclusive property of any professional group.